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Quantum Fluctuation Power Spectrum of Light Field in the Dielectric Interface System of Plasma / Dispersion Absorption Cavity

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Abstract:

In recent years, people have shown great interest in the quantum theory of light field in one-dimensional optical cavity composed of dispersive absorbing medium. However, up to now, only the vacuum in the cavity has been studied for one-dimensional dispersive absorbing medium symmetric cavity system in the existing literature, and there is no report of cavity loading. In this paper, the effect of plasma loading on the quantum properties of a dispersive absorbing dielectric cavity system is studied. The results show that the spatial distribution of the fluctuation power spectrum of the vacuum field in the system is significantly changed by the dielectric loading. The working state of the plasma loaded cavity is closely related to the selected optical field frequency. The results are valuable for the study of the quantum fluctuation power spectrum of the optical field in the dielectric interface system of plasma / dispersion absorption cavity.

Keywords: *Dispersive absorbing medium, Fuzzy,Plasma/Dispersion Absorption Cavity*.

I. INTRODUCTION

In recent years, people have shown great interest in the quantum theory of light field in one-dimensional optical cavity composed of dispersive absorption medium. They have studied the quantization method and quantum expression of electromagnetic field in dispersive absorption medium and its composite structure, and the reciprocal relationship and properties of photon operator and polarized phonon operator in composite medium system, which has certain practical significance for choosing the size and working frequency of optical cavity to reduce quantum noise and improve the working quality of optical cavity system.However, up to now, the existing literature only studies the cavity with vacuum in one-dimensional dispersive

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absorbing medium symmetric cavity system, and there is no report of cavity loading. This paper aims to investigate the influence of intracavity plasma loading on the system and the quantum properties of the optical field [1-3]. The results show that the working state of the plasma loaded optical cavity is closely related to the selected optical field frequency.

II. MODEL AND GREEN'S FUNCTION

The structure of one-dimensional symmetrical optical cavity composed of dispersive absorbing medium is shown in Fig. 1, where n (w) is the complex refractive index of the medium. Considering that the cavity space is filled with plasma, its refractive index n' is expressed as: $n'^2(\omega)=1-\frac{\omega_p^2}{\omega^2}$, where w and w_p are the angular frequency of light wave and the critical angular frequency index of plasma respectively [4-7]:

$$a=\frac{c}{b}+d+s_1^2 \quad (1)$$

$$\begin{cases} n(\omega)=\sqrt{\varepsilon(\omega)}=\beta(\omega)+i\gamma(\omega), |x|>l \\ n'(\omega)=\sqrt{\varepsilon'(\omega)}=\beta'(\omega)+i\gamma'(\omega), |x|<l \end{cases} \quad (1)$$

Among them, β, β 'and R、R1 are the refractive index and absorption coefficient of the medium respectively. When w > w_p, the plasma is transparent, (1) R1 = 0, when w < w_p, n' becomes pure imaginary number, (1) β' = 0.

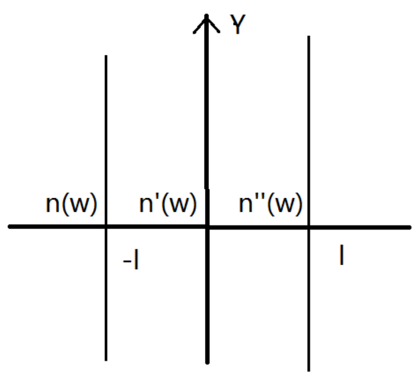

Fig 1: Plasma Loaded Symmetric Dispersive Absorption Dielectric Cavity

For the structure of Figure 1 expressed by formula (1), x＜- l is 1 area, x＜l is 2 area, x＞l is 3 area. Only considering the light field mode propagating at the interface of vertical medium, the Green function of magnetic vector potential in each region of the system can be obtained by using the theory of multiple reflection of light wave and electromagnetic boundary conditions. For example, when the field source and field point coordinates x ', x are in the same region, there are

$$G_{11}=\frac{1}{2ik}\left[e^{ik|x-x'|}+\frac{(n^2-n'^2)(1-e^{4ik'l})}{\sigma_c}-ik(x+x'-2l)\right],(x<-l) \quad (2)$$

$$G_{22}=\frac{1}{2ik'}e^{ik|x-x'|}+\frac{1}{2ik'\sigma_c}e^{2ik'l}\left\{\begin{array}{l} e^{ik'x}\left[(n'^2-n^2)e^{ik'x}x'+(n'-n)^2e^{2ik'l}\cdot e^{-ik'x'}\right]+ \\ e^{-ik'x}\left[(n'^2-n^2)e^{-ik'x'}+(n'-n)^2e^{2ik'l}\cdot e^{-ik'x'}\right]\end{array}\right\},(|x|<l) \quad (3)$$

$$G_{33}=\frac{1}{2ik}\left[e^{ik|x-x'|}+\frac{(n^2-n'^2)(1-e^{4ik'l})}{\sigma_c}e^{ik(x+x'+2l)}\right],(x>l) \quad (4)$$

Where

$$\sigma_c=(n+n')^2-(n-n')^2e^{4ik'l} \quad (5a)$$

$$k(\omega)=\frac{\omega}{c}n(\omega),k'(\omega)=\frac{\omega}{c}n'(\omega)=\frac{1}{c}\sqrt{\omega^2-\omega_p^2} \quad (5b)$$

And

$$kx=2\pi n\frac{x}{\lambda_0},k'x=2\pi n'\frac{x}{\lambda_0},k(\omega)=\frac{n(\omega)}{n'(\omega)}k'(\omega) \quad (5c)$$

The Green's function describes the space transfer property of the physical quantity, which is the basis of calculating the quantum fluctuation of light field.

III. POWER SPECTRUM AND NUMERICAL RESULTS OF QUANTUM FLUCTUATIONS IN ELECTRIC FIELD

The vector potential operator can be obtained by using Green's function

$$\hat{A}(x,t)=\int_0^\infty\left[\int_{-\infty}^{\infty}G(x,x',\omega)\hat{J}_n(x',\omega)dx'\right]exp(-i\omega t)d\omega+H\cdot C \quad (6)$$

Where $\hat{J}_n(x',\omega)$ is the dielectric quantum noise current operator, H·C is the Hermite conjugate term, combined with the relationship between potential function and field quantity.

$$\left\{\begin{array}{l}\hat{E}(x,t)=\int_0^\infty i\omega\hat{A}(x,\omega)exp(-i\omega t)d\omega+H\cdot C \\ \hat{B}(x,t)=\int_0^\infty\frac{\partial\hat{A}(x,\omega)}{\partial x}exp(-i\omega t)d\omega+H\cdot C\end{array}\right. \quad (7)$$

The electromagnetic field operator can be expressed by Green's function, where $\hat{A}(x,\omega)$ is the Fourier transform of $\hat{A}(x,t)$.

For the structure of fig. 1 described by formula (1), if the magnetic vector potential operator

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$\hat{A}(x,t)$ of the system is consistent with that of the uniformly dispersed absorbing medium in 1-3 zones, the Green's function of magnetic vector potential in each zone can be substituted into formula (6), and attention should be paid to the integration zone and subsection integration. The one-dimensional magnetic potential operator of the system can be expressed by polarized phonon operator. Furthermore, the regular reciprocity relation of electromagnetic field operators is used.

$$\left[\hat{A}(x,t),-\varepsilon_0\hat{E}(x',t)\right]=\frac{i\hbar}{s}\delta(x'-x) \quad (8)$$

The second quantization of the electromagnetic field in the dispersive absorbing composite medium system can be carried out. (1) s in the formula is the quantized area. With the help of this process, we can calculate the correlation function of the electric field.

The fluctuation of electric field and electric field in vacuum state (0) is given by formula (7)

$$\left\langle 0\left|\hat{E}(x,\omega)\hat{E}(x',\omega')\right|0\right\rangle=\omega\omega'\left\langle 0\left|\hat{A}^{+}(x,\omega)\hat{A}(x',\omega')\right|0\right\rangle \quad (9)$$

For the same space point, the magnitude of electric field correlation function depends on the power spectrum of electric field fluctuation

$$\left\langle 0\left|\hat{E}(x,\omega)\hat{E}(x,\omega')\right|0\right\rangle=S(x,\omega)\delta(\omega-\omega') \quad (10)$$

According to the fluctuation dissipation theorem, the power spectrum S (x, w) is

$$S(x,\omega)=2\hbar\omega^2 Im\left[G(x,x,\omega)\right] \quad (11)$$

Using formula (2) - (4), the power spectrum distribution of field fluctuation in three regions of the system is given as follows

$$S_1(x,\omega)=-\hbar\omega cRe\left\{\begin{array}{l}\frac{1}{n}+\frac{n^2-n'^2}{n\sigma_c}exp(2ikl)\square\left[1-exp(4ik'l)\right]\\ \square exp(-2ikx)\end{array}\right\},(x<-l) \quad (12)$$

$$S_2(x,\omega)=-\hbar\omega cRe\left\{\begin{array}{l}\frac{1}{n'}+\left[2\frac{n^2-n'^2}{n\sigma_c}exp(2ik'l)\right]cos(2k'x)+\\ \left[2\frac{(n'-n)^2}{n'\sigma_c}exp(4ik'l)\right]\end{array}\right\},(|x|<l) \quad (13)$$

$$S_3(x,\omega)=-\hbar\omega cRe\left\{\begin{array}{l}\frac{1}{n}+\frac{n^2-n'^2}{n\sigma_c}exp(2ikl)\square\left[1-exp(4ik'l)\right]\\ \square exp(2ikx)\end{array}\right\},(x>l) \quad (14)$$

From (12) - (14), it can be seen that S_1 (x, w), S_3 (x, w) and S_2 (x, w) all change with X and

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W; if n' = n, then it degenerates to the field fluctuation value in the dispersive absorbing homogeneous medium

$$S(x,\omega) = -\frac{\hbar\omega c\beta}{|n|^2} = \frac{\beta}{|n|^2} S_0(\omega) \quad (15)$$

Where $S_0(\omega) = -\hbar\omega c$ is the power spectrum of field fluctuation in vacuum

Let $w_p = \alpha w$, then n '= 1 - α^2. By using formula (12) - (14), the spatial variation of the power spectrum of the field fluctuation in the dielectric cavity system is calculated respectively in the case of α < 1 and α > 1, and the results are compared. In Fig. 2, n '= 0.6 and 2k'l = 6.6 π have been selected and calculated respectively as follows: (a) n = 2.0 + 0.02i, (c) n = 2.0 + 0.01i. The results show that the spatial refractive index of the cavity is changed only by the dielectric loading, and the spatial variation of the field fluctuation power spectrum in the cavity is not attenuated, which is equal amplitude oscillation; however, the field fluctuation power spectrum in the external region decays rapidly with the increase of the imaginary part of the external refractive index.In figure (3), n '= 1 - α 2, 2k'l = 1. I has been selected, and α = 1.2, 1.5 and (a) n = 2.0 + 0.02i, (b) n = 2.0 + 0.05i, (c) n = 2.0 + 0.05i respectively. At this time, n 'is an imaginary number. The results show that the power spectrum of the field fluctuation in the cavity region decays with the spatial change, and is no longer the equal amplitude oscillation. It is obvious that with the increase of ɔ, the attenuation of the field fluctuation power spectrum in the cavity region with the spatial variation is reasonable. However, the spatial variation law of the field voltage rise power spectrum in the external cavity area is similar to that in Fig. 2.

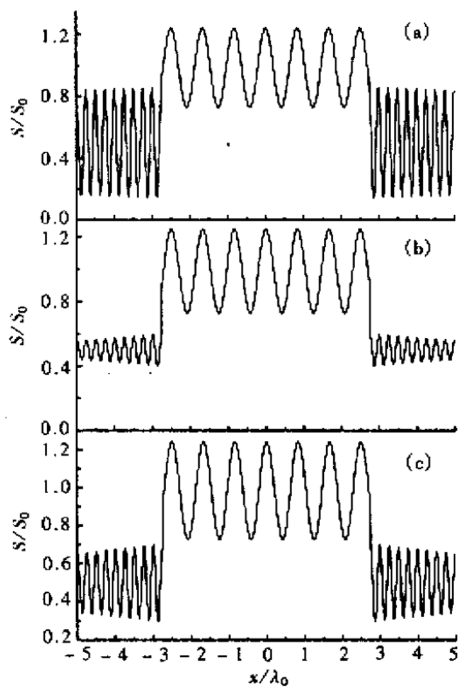

Fig 2: Spatial variation of power spectrum of electric field fluctuation

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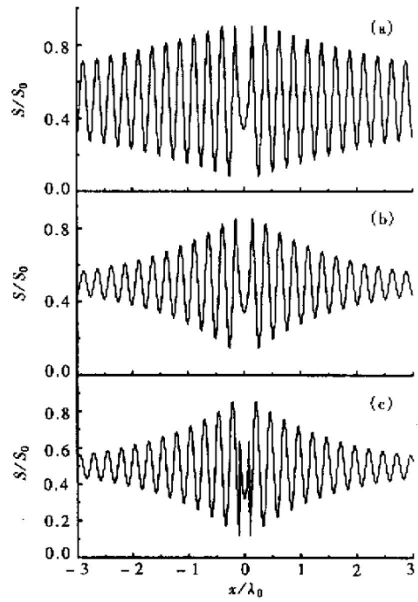

Fig 3: Spatial variation of power spectrum of electric field fluctuation

IV. CONCLUSION

The dielectric distribution and structure described in this paper have important applications in optical engineering and microwave technology such as optical fiber and microwave devices. The results are of practical significance for selecting the cavity size and operating frequency to reduce the quantum noise and improve the quality of the cavity system. In this paper, the effect of plasma loading on the quantum properties of a dispersive absorbing dielectric cavity system is studied. The results show that the spatial distribution of the fluctuation power spectrum of the vacuum field in the system is significantly changed by the dielectric loading. The working state of the plasma loaded cavity is closely related to the selected optical field frequency.

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